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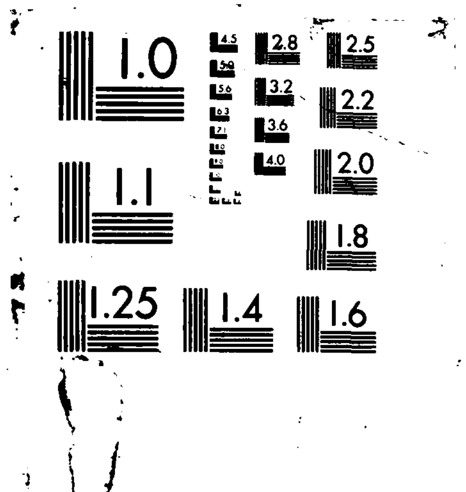

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A minicomputer-based set of instrumentation was purchased and configured for use in experimental studies involving transient seismic waves in soil, rock and pavement systems. This instrumentation is capable of performing: multi-channel data acquisition (up to 64) at very high speeds (1 MHz digitizer), intensive numerical computations rapidly on captured waveforms, and real-time graphical displays of the raw and analyzed data.

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TRANSIENT SEISMIC WAVES
IN SOIL, ROCK AND PAVEMENT

by

Kenneth H. Stokoe, II and Jiun-Chyuan Sheu

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ABSTRACT

A minicomputer-based set of instrumentation was purchased and configured for use in studies involving transient seismic waves in soil, rock and pavement systems. The heart of the system is a MASSCOMP (Massachusetts Computer Corporation) Model 5500 minicomputer. The key points of the instrumentation are: 1. the simultaneous recording of multiple data channels (up to 64) with high-frequency resolution (up to 100 KHz) on a limited number of channels, 2. the capability of being programmable so the data can be manipulated and analyzed in the time and frequency domains as they are being acquired, 3. the capability of visually displaying, plotting and/or printing the raw and analyzed data, and 4. the capability of performing analytical studies (such as inversion or forward modeling) on the data in the field.

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INSTRUMENTATION FOR THE STUDY OF TRANSIENT SEISMIC WAVES IN SOIL, ROCK AND PAVEMENT

1. INTRODUCTION

1.1 PURPOSE OF INSTRUMENTATION

Soil, rock and pavement materials behave like elastic materials at strains on the order of 0.001 percent or less. At these small strains, seismic waves can be used to evaluate the elastic moduli of such materials. For advances to be made in the basic understanding and uses of seismic testing, multi-channel high speed data acquisition equipment is required in the field. This equipment must also have the capability of handling extensive computer programs for intensive numerical manipulation of the raw data.

The purpose of this project is to purchase and develop state-of-the-art instrumentation for experimental investigation of transient seismic waves in soil, rock and pavement materials. Compression, shear and Rayleigh waves are to be measured with frequencies ranging from one Hz to about 100 KHz over time intervals ranging from about 0.0001 second to hundreds of seconds. The key points of the instrumentation are: 1. the simultaneous recording of multiple data channels (up to 64) with high-frequency resolution (up to 100 KHz) on a limited number of channels, 2. the capability of being programmable so the data can be manipulated and analyzed in the time and frequency domains as they are being acquired, 3. the capability of visually displaying, plotting and/or printing the raw and analyzed data, and 4. the capability of performing analytical studies (such as inversion or forward modeling) on the data in the field.

1.2 STATE-OF-THE-ART IN 1983-84

At this time (1983-84), state-of-the-art collection and processing of field seismic data for engineering analyses involves recording seismic signatures at test sites with waveform analyzers storing the data on magnetic cartridge tapes or floppy disks. The stored records are then brought back to the laboratory and data are dumped to computers for additional processing. (At The University of Texas, we have used the dual cyber mainframe computer for data processing.) This way of handling seismic data has several drawbacks. The first one is that it is tedious and time consuming to transfer data from one machine to another. In addition, more data transfer processes lead to a higher possibility of data loss and data errors which in turn requires more time and resources to try to recover.

The second drawback is that it precludes the possibility of examining semi-processed and processed data right at the testing site. At present, all data collected in the field are raw time-domain and raw frequency-domain data. Since our data manipulation capability is limited by the equipment (the waveform analyzer), it is only possible to examine the quality of raw time-domain and raw frequency-domain data at the test site. In general, phases of cross power spectra, the basis on which dispersion curves are constructed, are important data collected in the field, and coherence functions are used for data quality control. However, the quality of frequency-domain data sometimes reflects the quality of dispersion curves only in a very transparent fashion. As a result, some data collected in the field may later be found to be of low quality or even lack the data required for the in-house data reduction stage. Yet, at this stage, options for improving the data quality are very limited.

Another drawback is that most waveform analyzers currently available on the market (in 1983-84) have only two sampling channels. Therefore, only two receivers can be used at a time. Seismic testing is better performed with multiple receivers (from six to 24), hence multiple channels. If a waveform analyzer could be equipped with enough sampling channels (six or more) so that signals from a series of receivers could be recorded at one time and frequency analysis could be performed between any selected channels, much less time would be required to perform the tests and much more accuracy would result.

All of these facts point to the need for field equipment that is capable: of doing multi-channel data acquisition at very high speeds, of performing intensive numerical computations rapidly on captured waveforms, and of having graphical capabilities which can display the results immediately. Review of the technology in 1983-84 suggests that a minicomputer suits these needs the best. As a result, a MASSCOMP model MC5500 minicomputer was selected as the heart of the instrumentation purchased.

In the following sections, the capacity, software, and hardware configurations of this minicomputer are briefly outlined. The present operating level and software development are discussed. Additional equipment purchased to support the minicomputer and seismic measurement processes are also discussed. Immediate and final goals of software development and uses are presented as a conclusion.

2. GENERAL BACKGROUND OF THE MASSCOMP MINICOMPUTER

MASSCOMP (Massachusetts Computer Corporation) is a Massachusetts based computer manufacturer which produces minicomputers for scientific and business applications. The Model MC5500, listed as item 1 in Table 1, is designed specifically for scientific applications and integrates both data acquisition and numerical computation capabilities into one unit; the key reason for selecting this unit. With such integrated capability, it is possible to use this computer for sampling and analyzing seismic data in the field efficiently and effectively.

The MC5500 computer was installed in April, 1984. Since then, both the software and the hardware have gone through several revisions. The hardware was finally fully operational in December, 1984. However, system software bugs (errors) appeared frequently from the beginning of its operation and posed a significant hurdle to software development. The system performance was finally stabilized with the installation of the most recently released version of the operating system which became available in June, 1986 and was installed in December, 1986.

A software supporting contract was not purchased in any stage of the software development process because of lack of funds. As a result it has been a tremendous task for the program designer (Mr. J.C. Sheu) to develop programs because the only way to resolve system problems was by trial and error. A great deal of effort has been expended due to the lack of a software supporting contract. Fortunately, even with a lot of hardware and software problems associated with the computer system throughout the first three years of operation, there are quite a few accomplishments which allow the Model MC5500 to be used for seismic data

TABLE 1. FINAL EQUIPMENT INVENTORY OF GRANT AFOSR-83-0253 U.T. ACCT. NO. 26-0293-1481

Line Item	Quantity	Item Description	Cost
1	1	Data Acquisition & Presentation System with various components, associated and interfacing equipment: PO# U-4-1001-V; VO# L090281; dated June 22, 1984; Purchased from Massachusetts Computer Corporation (MASSCOMP) in March 1984. Inventory numbers 386668 thru 386673, 386722, and 386723.	$55,551.10* $ 3,605.90
2	1	Graphics Plotter with HP-IB Interface: Model 7470A; S/N 2308A70769; PO# UT-4-30756; VO# L092254; dated June 29, 1984; Purchased from Hewlett Packard in June 1984; Inv. # 389304.	$ 712.00**
3	1	Data 6000 Universal Waveform Analyzer: S/N 2117; PO# UT-4-17062; VO# L051648; dated Feb. 27, 1984; Purchased from Data Precision, Div. of Analogic Corp. in Jan. 1984; Inv. # 385877.	$12,355.00
4	1	Dual Floppy Disk Drive: Model 681; S/N 1156; PO# UT-4-17062; VO# L051648; dated Feb. 27, 1984; Purchased from Data Precision, Div. of Analogic Corp. in Jan 1984; Inv. # 385878.	$ 2,716.00
5	1	Programmable Universal Counter: Model 5334A; S/N 2350A00797; PO# UT-4-28201; VO# L082724; dated May 31, 1984; Purchased from Hewlett Packard in May 1984; Inv. # 388338.	$ 2,800.00
6	1	Programmable Digital Voltmeter: Model 3456A; S/N 2201812206; PO# UT-4-28201-CM; dated Nov. 1984; Purchased from Hewlett Packard; Inv. # 389958.	$ 3,800.00
			$81,540.00
			$10,000.00*
			$91,540.00

* Total cost of this item was $69,157; however $10,000 was charged to UT Account No. 20-3095-2080, Civil Engr Special Equipment 1983.

** Total cost of this item was $821.25; however $109.25 was charged to UT Account No. 26-0261-2480, Grant AFOSR-83-0062.

processing. The unit is, however, located in the laboratory (not in a field vehicle) at this time.

3. COMPUTER ARCHITECTURE

The MASSCOMP MC5500 computer achieves balanced performance without bottlenecks by off-loading many functions from the central processors. Co-processors carry the burden of graphics, data acquisition, floating point arithmetic, and vector arithmetic. Due to the presence of a physical cache, most memory accesses involve no wait states. The MC5500 computer uses the triple bus design shown in Fig. 1. Three buses are used for information transfer. They are the memory interconnected (MI) bus, the multibus, and the STD+ bus.

The MI bus operates at 8 Mbytes/sec and supports up to 8 Mbytes of error checking and correcting memory. The central processing unit (CPU) module accesses system memory through the use of this high-bandwidth bus. Both an FP-501 floating point accelerator and an AP-501 vector processor also operate on this MI bus.

The multibus is the system peripheral bus. It operates at 3 Mbytes/sec. The peripherals include a MASSCOMP data acquisition and control processor (DACP), an independent graphic system, a disk controller, and a tape controller. The separation of the memory bus and the peripheral bus helps prevent a bottleneck that would otherwise constrain the system throughout. The CPU module interfaces to the multibus through a hardware multibus adaptor designed for high speed direct memory access (DMA) transfers.

The STD+ bus is an enhanced version of the industrial standard STD bus. This bus operates at 2 Mbytes/sec and is connected to the multibus

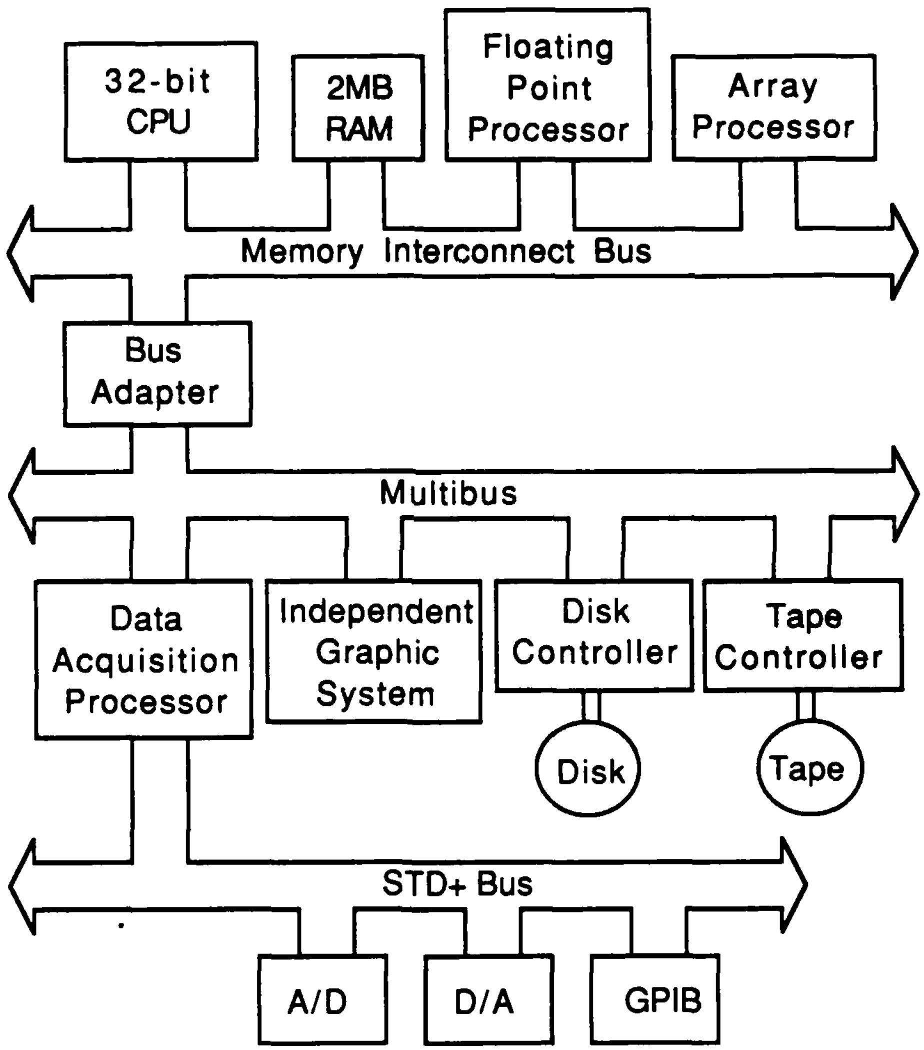


Fig. 1. Architecture of MASSCOMP MC5500 Minicomputer.

through the DACP. It is designed as the combination of two STD buses side-by-side with shared address lines and separate data paths. All MASSCOMP-supplied data acquisition modules, as well as commercially available STD devices, are supported by this bus. Digital-to-analog (D/A) convertors, analog-to-digital (A/D) convertors, and a general purpose interface bus (GPIB) are currently connected to the STD+ bus.

4. HARDWARE CONFIGURATION OF THE MC5500 MINICOMPUTER

4.1 BASIC HARDWARE

The MC5500 is a 32-bit computer system incorporating very large scale integration (VLSI) technology from a variety of vendors through the system. The CPU module includes a Motorola MC68010 processor and Motorola MC68000 processor working in tandem at 10 MHz. Substantial hardware is used to support a demand-paged, virtual-operating system with 4-Kbyte pages. There are 16 Mbytes of user virtual address space. A 1024-entry translation buffer stores the most recently used addresses, thereby minimizing average address translation time. A user can override certain memory management mechanisms, for example, by locking programs into physical memory to prevent swapping and paging which is a critical feature for real-time programming in the UNIX environment. It is also possible to map multibus addresses, such as a device register, directly into the virtual address space.

The MC5500 uses 4-Kbyte, one-way-associate cache, operating on physical addresses, to eliminate most of the need for wait states. By taking advantage of normally unused CPU cycles, the cache anticipates the instructional needs of the processor and "reads ahead." For common applications, 90 percent of all instruction and data fetches come from the cache. Since there are no processor wait states when reading from the cache, this represents a substantial performance gain. Physical memory consists of 64-Kbyte dynamic random access memories (RAMs) on 1-Mbyte boards that communicate through the MI bus. The memory can detect multiple-bit faults and correct single-bit faults. Total physical memory is expandable to 8 Mbytes. Two Mbytes of physical memory are currently installed in the system.

4.2 OPTIONAL HARDWARE

An FP-501 floating point accelerator and an AP-501 vector processor are currently installed in the system. The floating point accelerator can increase the floating point performance to 924,000 Whetstones/sec. It features 24 sets of 32/64-bit registers. Data types supported are 32-bit integer, 32-bit reaL, and 64-bit real. The AP-501 vector processor enhances the performance for many scientific applications involving vector and array calculations. It handles single-precision floating point computation. Both the FP-501 and AP-501 operate on the high-speed MI bus with direct access to system memory and greatly increase the system efficiency.

The MC5500 supports an independent graphics processor (IGP). It consists of a separate MC68000 processor with 256 Kbyte of graphics software memory, 2 frame buffers, and a 6-plane raster image memory. A 13-in. color monitor with 640x480 pixel resolution is currently installed. An optical mouse and 117-key keyboard are also in use.

Mass storage of the system includes a 27-Mbyte, 2.25-in. hard disk, an 80-Mbyte, 8-in. hard disk, a 1-Mbyte floppy disk drive and a 1/4-in. cartridge tape driver with a capacity of 50 Mbyte of storage per tape.

These devices provide ample room for a smooth system operation as well as convenient data exchange with other computer systems.

The data acquisition and control processor (DACP) is a 125 ns/cycle bit-slice processor operating on the multibus. The input data transfer rate is 2 Mbytes/sec. It also can make real-time data dependent decisions. Special operating system features make it possible for acquired data to be written to disk at very high speeds.

The analog-to-digital (A/D) convertor has a 1-MHz transfer rate with 12 bits of resolution. The maximum number of channels that can be sampled is 64 single-ended or 32 differential channels.

An 8-channel digital-to-analog (D/A) convertor is also available in the system. It operates at maximum frequency of 500 KHz with 12 bits of resolution.

A general purpose interface bus (GPIB, also known as HPIB, IB-488 or IEEE-488) is installed in the system to provide convenient communication among a variety of instruments and computers. The GPIB is a bit-parallel, byte-serial, standard interface bus. The maximum data transfer rate is 500 Kbyte/sec. This interface bus enables the MC5500 to control all devices with GPIB interfaces and is vital to computer-aided laboratory testing. Three, RS-232 serial ports are available for connecting terminals, printers, plotters, modems and other peripherals with the same serial ports.

5. SYSTEM SUPPORTED SOFTWARE

The MC5500 uses a real-time UNIX operating system. This is a modified version of the UNIX operating system. The modification is necessary because UNIX is a time sharing operating system, but data acquisition and other laboratory instruments' control are real-time jobs. To prevent all real-time jobs from being interrupted, MASSCOMP modified the existing UNIX operating system. The real-time enhancements include a provision for special real-time program properties such as system calls that lock programs in primary memory, asynchronous system traps (AST) for extremely fast and error free interprocess communication and contiguous files allow high-speed disk access.

MASSCOMP supports a complete graphics library, data acquisition library, array processor library and other necessary libraries for software development. The present system supports both FORTRAN77 and C compilers.

For the purpose of digital signal analysis, a software library, the interactive laboratory system (ILS), was purchased from Signal Technology Inc. in 1985 on another project. This library provides a full line of interactive programs for signal processes such as Fast Fourier Transformation (FFT), spectral analysis functions, design and application of filters, etc. A digital signal processing library edited by the Institute of Electrical and Electronic Engineers (IEEE) is available in the system too. These software packages are very important to the seismic system development because it reduces the load on the system software designer so that he or she can concentrate on algorithm development rather than routine program coding.

6. CURRENT OPERATING LEVEL

For the purpose of field data sampling, several multi-channel data acquisition programs were developed based on different data transfer techniques. It is possible to sample a different number of channels at desired frequencies. A major problem unsolved at present is the triggering problem. An external trigger which needs some hard-wiring can be implemented without too much difficulty, but the internal trigger and pre-trigger functions, which are necessary for many seismic tests, need intensive programming and are yet to be implemented.

The use of the GPIB interface has been very successful. Several programs which are used to communicate with other instruments through this GPIB were developed. A GPIB debugger manufactured by National Instruments Corporation was purchased for decoding and debugging any GPIB interface problems. With the help of this GPIB debugger, it is even easier to make use of the GPIB interface.

Several data processing programs dedicated to seismic testing with surface waves were developed. These programs include transferring data from and to a waveform analyzer, disk driver, or other computer and necessary instruments, field data filtering, averaging, and plotting. An inversion program for surface wave testing which resides in the mainframe computer at The University of Texas at Austin is available on the MC5500 after some modifications. Post data process programs such as tabulating and plotting end results are also available in the system.

7. OTHER EQUIPMENT PURCHASES

7.1 ON THIS PROJECT

Five other pieces of equipment were also purchased on this project for use in support of the MC5500 minicomputer. This equipment if listed as items 2 through 6 in Table 1. The graphics plotter (item 2) is simply used for plotting purposes. The waveform analyzer (item 3) and floppy disk drive (item 4) are used as a portable, 4-channel field analyzer with which seismic waveforms can be recorded for subsequent processing with the MC5500. The universal counter (item 5) and digital voltmeter (item 6) are primarily used with other existing electronics for "trouble shooting" and "debugging" the A/D and D/A components of the MC5500.

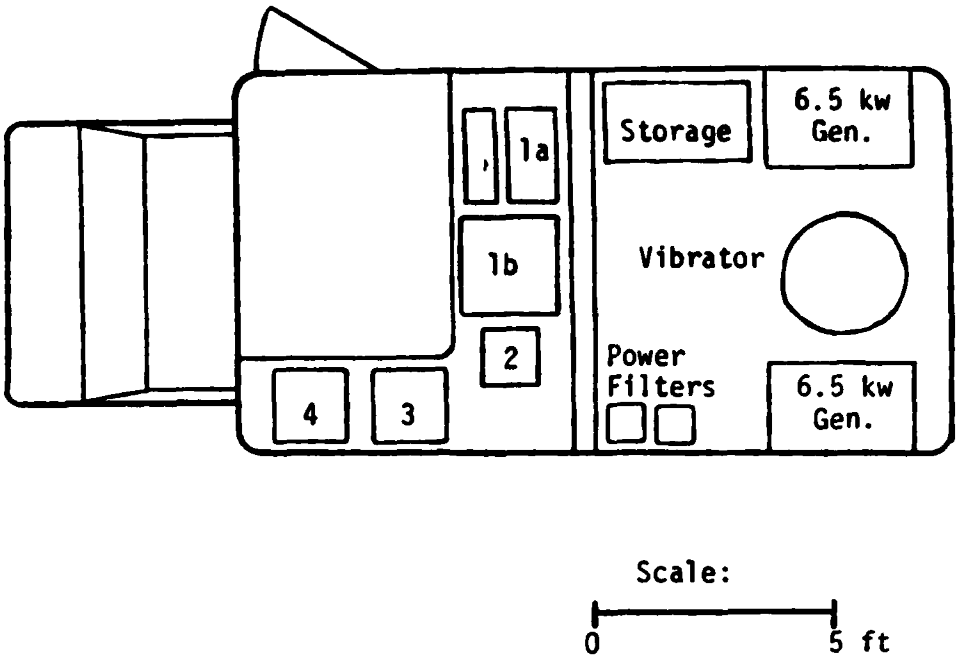
7.2 PURCHASED BECAUSE OF THIS PROJECT

Because of this equipment grant, the Civil Engineering Department and College of Engineering have contributed an additional $30,000 for development of a field vehicle for use in seismic testing. The vehicle is illustrated in Fig. 2 and is a 1-ton Ford E350 Cutaway truck body with a 15-ft Utilimaster van body mounted on the frame. A partition separates the van body into two areas and provides a convenient location for gauges and instrumentation. The van body is equipped with a Coleman 1-ton air conditioning system, two 6.5 KVa Onan electrical generators, and two Topaz power filters. With this system, the MC5500 minicomputer can be housed in a constant temperature environment and supplied with properly conditioned electrical power.

In addition to the equipment listed above, a 250-lb electro-mechanical vibrator is presently being installed in the rear of the vehicle. The vibrator will be used to generate seismic waves with known frequencies and will increase the quality of data obtained with in-situ seismic techniques such as the crosshole and Spectral-Analysis-of-Surface-Waves methods.

8. IMMEDIATE AND FUTURE DEVELOPMENT GOALS FOR THE MC5500

The MC5500 has a great graphics capability which was not employed on this project due to the complex nature of its graphics system and



Data Acquisition and Reduction Equipment

1. MASSCOMP Minicomputer
2. Printer/Plotter
3. Waveform Analyzer
4. Additional Support Electronics

Fig. 2. Plan View of Seismic Vehicle.

software bugs. The newest operating system and graphics library (installed in December, 1986) seem to have considerably fewer bugs. It will be delightful to have this powerful graphics system fully developed.

Field spectral analysis is a critical part of future seismic testing. As a result, a data acquisition program integrated with spectral analysis and graphics display functions is needed. A present, this type of program is not available in the system and is an immediate goal for software development.

The final goal is a mobile field system with the capability of graphically displaying properties profiles during testing at the test site. This system requires integration into one program or the combination of a series of programs of: data acquisition, spectral analysis, graphics display, data filtering, inversion, and post data processing. All of these tasks can be done solely by the MC5500 and will be implemented in the near future. The mobility of the system will come from integrating the MC5500 and support electronics into the field vehicle. This task will hopefully be accomplished by summer, 1988.

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